International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 527–538

MECHANICAL CHARACTERIZATION OF ALUMINUM 6061 WITH B_4C AND HIGH ENTROPY ALLOYS

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ABSTRACT

Aluminum matrix-based materials are widely used in aircraft, automobile industries due to its lightweight to strength ratio. Globally, researchers focus on developing the materials with lower density with high strength. In the present study, Aluminum 6061 is reinforced with B_4C and High entropy alloys (HEA) particles. The specimens were prepared by the stir casting process. Three different samples were prepared by varying the composition of the B_4C particles as 1% with 0.2% of HEA, 2% of B_4C with 0.4% HEA and 3% of B_4C with 0.6% of HEA. The mechanical characterization of samples showed a considerable increase in the hardness withthe increase of the reinforcements. The Aluminum 6061 with 2% B_4C and 0.4% HEA were shown comparatively better tensile and hardness property, as compared to the other two samples.

KEYWORDS: Aluminum 6061, Stir Casting, Mechanical Characterization, Hardness & Tensile Strength

Received: Jul 01, 2019; **Accepted**: Jul 29, 2019; **Published**: Sep 19, 2019; **Paper Id.**: IJMPERDOCT201946

Original Article

INTRODUCTION

In modern automotive industry, metal matrix composites (MMC) play a vital role due to their lightweight. If more than one reinforcement material is added, then those are called Hybrid Metal Matrix composites [1]. They are considered as a better alternative than single reinforced particle composite due to the added effect of the other reinforcement material [2][3]. Aluminum Metal Matrix composites (Al-MMC) are preferred for their high strength to weight ratio, high specific modulus, high wear resistance etc., Automobile applications of Al-MMC include pistons and cylinder liners, brake rotors, etc.[4][5]. Al-6061 alloy has been widely used in construction as well as in the Automobile industry, due to its medium strength, low cost, high corrosion resistance, good weldability, etc.[6][7]. Properties such as high stiffness, high strength to weight ratio and high resistance to wear are achieved by the usage of Boron Carbide(B_4C) [8]. Higher the percentage of Boron Carbide particles, higher wear resistance of the material[9]. In the present work, a novel attempt has been made to make a hybrid composite by reinforcing B_4C and high entropy alloy with Al-6061. According to the definition of Yehet al.,[10], high entropy alloys are those, in which, at least five principal elements are mixed together in near equimolar ratios varying the concentrations between 35% and 5%. It has been discovered in his study that greater stability of solid solutions of many elements has been observed due to their large mixing entropies. Properties such as high strength, high fatigue resistance, and high fracture toughness are being exhibited by High Entropy alloysetc.[10], [11]. Previously, many

experimental and numerical works are carried out to know the behavior of aluminum when it is reinforced with other material. Saravananet al.,[12] produced the specimen of hybrid Aluminium reinforced with RHA with 3%, 6%, 9%, 12% weight composition using stir casting method to study its mechanical properties. An increase in properties was observed such as Tensile, Compressive strengths as well as hardness with the increase in weight %, whereas ductility decreases with increase in weight %. However, tensile strength decreases after 12% weight due to poor wettability.

K. Rajkumar et al., [13] performed the microwave heat treatment on B4C reinforced Al (6061) and observed its mechanical properties. It was discovered that the mechanical properties were better for the microwave heat-treated composites &the time required for this process is much lesser than the time needed for conventional heat treatment. Cutting force for the composite was reduced and the surface finish was much better for the microwave heat treated composite. Pragnya Rani et al., [14] investigated the microstructure and properties of Eggshell reinforced Al 6061 which was fabricated by using Powder metallurgy method. As the % of egg shell is increased, its hardness increased while properties such as electrical conductivity and density are reduced. There was a good bonding of reinforcement with the matrix and no gaps were present. Vinay Kumar et al., [15] studied the correlation between rpm and wear rate and comparison of mechanical properties of Al 6061, Mg 4%, Fly ash and Al 6061, Mg 4%, Graphite 4%, Fly ash MMC's. The matrix was prepared by making use of stir casting. Upto 15%wt of Fly ash tensile strength increases and then decreases and hardness of sample having 20% fly ash is maximum. By adding 4% of graphite, both Tensile strength and spec: wear rate decreases, though it smoothens machining. Kenneth Kanayo et al., [16] fabricated a hybrid compositewith Al-Si-Mg as matrix material and Rice Husk ash (RHA) and (Al2O3) as reinforcement through stir casting route. The decrease in mechanical properties such as Tensile strengthand hardness was observed with the increase in percentage of RHA. A comparison of RHA with other compositions concluded that 2%. RHA higher Specific strength, % elongation and fracture toughness are higher than a single Al2O3 and RHA can be used to develop low-cost high-performance Al hybrid composites. Anand Kumar et al., [17] fabricated the Al-4.5% Cu/10TiC using In-situ method through stir casting route and studied its mechanical properties. The material properties were found to be improved by using TiC as reinforcement. The fracture surface showed small dimples which indicated ductile fractures. Johny James et al., [18] studied the machining and mechanical properties hybrid AluminiumMMC by reinforcing TiB_2&SiC by mechanical stirring and gravity casting method. It is found that max limit for TiB_2 is 2.5% and SiC is 10%, above which cluster is formed in the matrix. Material properties increased, but with the addition of TiB_2 a reduction was observed. Due to high adhesive and abrasive action high wear rate has been noted. Studies on tribological and mechanical properties on single and multi reinforced Aluminum matrix prepared through stir casting route were conducted by Himanshu Kala et al., [19]. Yield strength and elastic modulus are improved but hardness was reduced due to the addition of B4C, SiC, and Al2O3. The addition of graphite increased tensile strength and elastic modulus but decreased the hardness and friction coefficient and this was aided by organic RHA to obtain better tribological and mechanical properties. This was further supported by the work of Suresha et al., [20] in which he studied the tribological behavior of Al composite with SiC and particulate graphite. For this study, method of fabrication was Stir casting. It was observed that wear rate was directly proportional to sliding speed and applied load, but inversely proportional to speed. Optimal reinforcement % was found to be 7.5%. David et al., [21] fabricated a Hybrid composite (Al/6061&SiC+Flyash) usingstir casting method, and studied its sliding wear behavior and microstructure. It is observed that by the addition of reinforcements, tensile strength and hardness of the composite were enhanced. The presence of FA in Silicon Carbide performs prevented the formation of Al_4C_3 phase. Rahman et al., [22]., researched on stir cast silicon carbide (SiC) reinforced AMCs and it was observed that 20% SiC gave maximum tensile

strength and hardness, and wear resistance. The SiC particles dispersed non-homogenously and clustered together as observed from the microstructure. Bharath et al., [23]., investigated Al-6061 alloy reinforced with alumina (Al2O3). As the weight % of Al2O3 increased its hardness also increased. Yield and Tensile strength were higher in the case of the composite compared to ductility. Weight loss due to wear was observed to be less in the composite and the distribution of alumina was uniform throughout the matrix. Pawar et al., [24] fabricated spur using SiC reinforced Al Metal matrix composites. SiC was added in mass ratio of 2.5%, 5% and 7% and 10%. For the composition with 10% SiC the hardness was observed to be the highest. FEA analysis shows that the highest stress value was obtained at the tips, and this can be used to various power transmitting devices such as gears. Jebeen et al., [25] prepared SiC reinforced AMC by stir casting to investigate its microstructure and other properties. It was observed that SiC particles enhance the micro-hardness and UTS of the composite &fracture mode was changed from ductile to brittle as the SiC content is increased. The matrix alloy grains have been refined by SiC particles which helped in proper bonding to the matrix. Prakash Rao et al., [26] fabricated a composite of Al6061 using stir casting method & investigated its physical and machining behavior. They observed that cutting speed and feed rate were influencing the built-up edge formation. And at low speed and feed the BUE [Built up edge] formation was also low. Siddesh et al., [27] researched the properties and wear rates of $Al2219/B_4C/MoS_2$ composites. They observed that density and micro hard increased with the increase in % reinforcement, and it reduces the wear rate in the abrasive mechanism. The tensile strength and yield stress were observed to be decreased with increase in MoS_2. Keneth et al., [28] experimented on the corrosive properties of Al-Mg-Si hybrid MMC. He showed that by adding RHA and SiC corrosion resistance of the matrix is increased. The properties of this composite such as resistance to wear and CoF were comparable with that of SiC reinforced Al-Mg-SiC matrix. BartoszHekner et al., [29] worked on Al-SiC hybrid composites with carbon additives made by using hot pressing. The frictional behavior was observed to be improved at the room as well as elevated temperature. For a particular tested range of carbon, wear rate was found to be independent. Kulkarni et al., [30] studied the variation in mechanicalproperties of Al356 alloy due to the addition of flyash and alumina. The addition of large amount of flyash improved some of the properties such as compressive strength but it reduced the density of the composite. Sijo et al., [31] used simulation and numerical methods to predict the characteristics of Al-SiC composite. Mechanical properties are increased by adding reinforcement to a certain level. Due to the addition of reinforcement, fracture toughness of the composites decreased. Sharifi et al., [32] tested the sliding wear behavior of Al matrix nanocomposites containing varying percentages of Al_2O_3-AlB12 particles. Wear resistance increased as the addition of reinforcement increased but after a certain sliding distance, CoFstarted declining and achieved a constant value later on. Baradeswaran et al., [33] analyzed the mechanical behavior and factors influencing wear behavior of composite under dry sliding conditions through RSM and mathematical modeling. High hardness and good % elongation was obtained in the AMC. Although it is significantly lesser than base metal, it was observed that wear resistance increased with increasing the wt% of B4C and Gr particles to 10% & 5% respectively. Huber et al., [34] explained the anomalies in the thermal expansion behavior of 70% SiC reinforced aluminum matrix composite for high power electronic modules. It was observed that heating the alloy beyond 300^{o}Credissolves the Si atoms which decrease the thermal expansion. The thermos elastic deformation was seen more in low-temperature areas. Elomari et al., [35] studied the thermal expansion behavior of isotropic MMC reinforced with SiC particle. The matrix was prepared by High-Pressure Vacuum-assisted Infiltration. It was observed that thermal expansion coefficient of MMC lay within elastic bounds derived by Schaoery's analysis. Thermal expansion of the composite increased with increase in particle size. High-quality porosity free composite has been produced using high-pressure infiltration process. These high pressures are achieved by creating vacuum. In all the above works aluminum exhibited enhanced mechanical properties. The present work FeCoNi $(AlSi)_{0.5}$ HEA and B_4C are used as

reinforcements. B_4C interaction with Aluminum matrix is known, but the interaction of HEA with Aluminum matrix in presence of B_4C was not reported in any published literature. Stir casting process adopted as the manufacturing process for the fabrication of the hybrid composites [36][37]. Stir casting is a low cost and efficient technique and one of the simplest ways used to produce Aluminum Matrix Composites. To achieve a proper distribution of reinforcement vortex method is used in stir casting whereby stirring vigorously a vortex is generated at the surface of the melted material and reinforcement is added to the melt simultaneously as the stirring take place [38].

MATERIALS AND METHODS

Preparation of Composite

In this study, Aluminum-6061, whose chemical composition given in table 1 is used as a matrix material. The alloy widely used in aircraft and marine industries. Commercial grade B_4C with a grain size 60μmand High Entropy Alloy of composition FeCoNi $(AlSi)_{0.5}$with a grain size 100μmhas been used as reinforcement material. The composites were synthesized by dispersing high entropy alloy and B_4C with various weight fractions using the stir-casting process. Composite was fabricated using varying weight percentages of reinforcement material shown in table 2. Al-6061 ingots were melted at a temperature of 800ºC [14] and for degasification of molten liquid, nitrogen are used. To avoid defects such as solidification shrinkage, molds were preheated at 550□C in a furnace for 3 hrs. The reinforcements were added to the molten aluminum periodically, and during mixing of the reinforcements, a stirrer is used to create vortex to obtain complete mixing. Then the molten substance was heated at 800ºC at for over an hour and it was transferred to molds. Mould kept at ambient temperature for duration of 12 hours for solidification process. These as-cast composites were homogenized at 570ºC for 8 hours and normalizedto achieve uniform distribution of the reinforcements. Tensile test specimens were prepared from the fabricated composites as per ASTM E8, using a numerically controlled wire electrical discharge machine (EDM), as shown in figure 1.

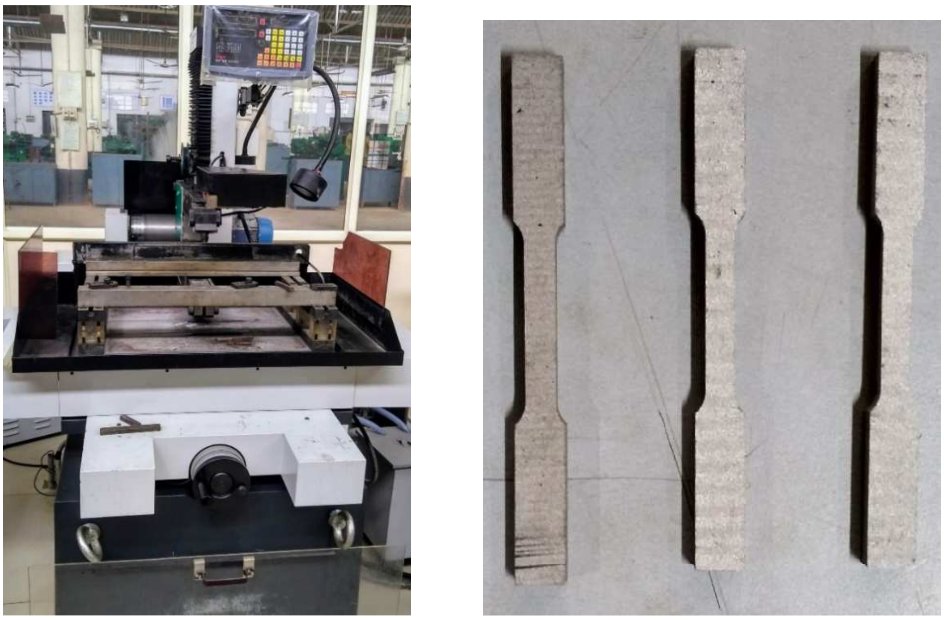

Figure 1: Tensile Specimens Machined using Wire EDM.

Table1: Chemical Composition of Al-6061

Component	Al	Mg	Si	Cr	Cu	Fe	Mn	Ti	Zn
Wt %	95.8 - 98.6	0.8 - 1.2	0.4 - 0.8	0.04 - 0.35	0.15 - 0.4	0.7	0.15	0.15	0.25

Table2: Different Specimens with Varying in the Compositions of B_4C and HEA

Specimen Designation	Reinforcement (wt %)		Al-6061(wt %)
	B_4C	HEA	
S1	1	0.2	98.8
S2	2	0.4	97.6
S3	3	0.6	96.4

RESULTS AND DISCUSSIONS

Tensile Properties

Tensile test of high entropy alloy and B_4C reinforced hybrid aluminum matrix composites were conducted on 50 kN BiSS universal tensile testing machine as per ASTM E8, as shown in figure 2. Tests were carried out displacement mode at a feed rate of 2 mm/min. Five replicate samples were used in the test to obtain average failure stress and strain of the specimens.

The average failure stress and strain obtained from the tensile test of Al-6061 hybrid composites is shown in figure 3 and 4, respectively.

Figure 2: Tensile Test of the Hybrid Composite.

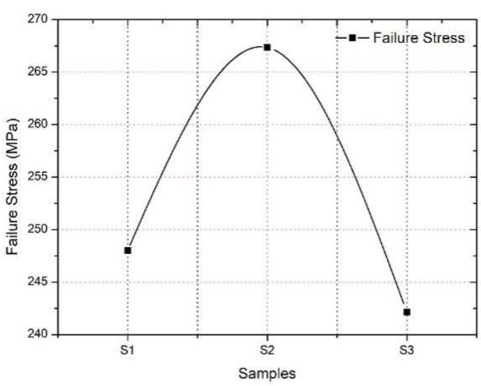

Figure 3: Average Failure Stress of Different Hybrid Composites.

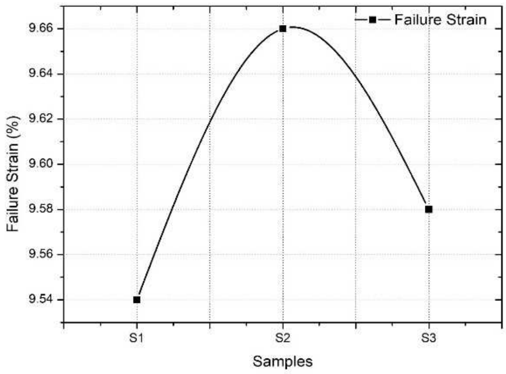

Figure 4: Average Failure Strain of Different Hybrid Composites.

The failure stress and failure strain showed an increment with an increase in the percentage of B_4C and HEA. At 2% of B_4C and 0.4% of HEA, the optimum tensile property for the material is obtained with failure stress of 268MPa, and which falls near to the tensile property of pure Al-6061 matrix material. As the percentage of B_4C and HEA increased specimens exhibited lower tensile properties as shown in figures 3 and 4. Published literature has shown that there is significant variation in the tensile properties when aluminum is reinforced with B_4C particles [39][40]. The addition of a lower weight percentage of B_4C and HEA to Al-6061 reduces the failure stress value because of the poor distribution of the reinforcement phase. The higher weight percentage of B_4C (2%) and HEA (0.4%)exhibited better tensile properties because of the better distribution of the reinforcement phase.

Hardness Test

The Brinell hardness test was conducted on hybrid metal matrix composites to understand the effect of the reinforcement phase on the ductility of the material. Brinell hardness test performed on all the three different composition of the material. Published literature revealed that there is a significant change in hardness of material due to the addition of B_4C particles. The value of Brinell hardness increased with increases in the weight percentage of the reinforcements [41][42][43]. Figure 5 shows the variation of hardness value of the hybrid composites with respect to the variation of weight % of reinforcement materials.

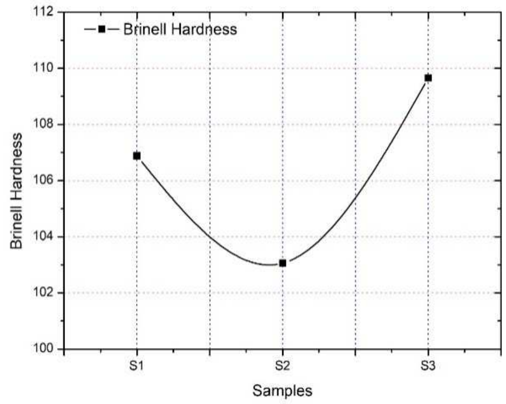

Figure 5: Average Brinell Hardness Number of Different Hybrid Composites.

The specimen prepared with 2% B_4C and 0.4% HEA showed least Brinell hardness value (103BHN) with the increase in failure stress as shown in figures 4 and 5. The maximum hardness value of 109.5 BHN obtained for a specimen with a high percentage of B_4C (3%) and 0.6% HEA. Specimen S2 showed a mean hardness value (107 BHN) as compared to other two specimens as shown in figure 5.

Microstructure Analysis

SEM imaging was conducted on the fractured surface post tensile test to analyze the surface morphology. Figure 6 (a), (b), (c) shows the SEM images of the fractured surface of three different samples with different weight fractions of B_4C and HEA.

SEM images of 1% B_4C, 0.2%HEA (figure 6(a)) reinforced shows agglomeration of B_4C particles and large void content. The presence of void content and poor distribution of the reinforcement phase resulted in lower failure stress and lower hardness values. SEM images of 2% B_4C, 0.4% HEA show a uniform distribution of particles, which resulted in high failure stress with the presence of small void content as compared to 1% B_4C, 0.2% HEA samples. Reinforcement of Aluminum with 3% B_4C, 0.6%HEA resulted in higher Brinell hardness number as compared to base matrix material due to the absence of void content as shown in figure 6 (c). The energy dispersive spectrometry (EDS) analysis of 3% B_4C, 0.6% HEA reinforced hybrid composites shown in figure 7. The material shown presence of 80.31% Al, presence of Ferrous (2.31%) confirms the incorporation of HEA with the matrix material. The EDS analysis also showed the presence of 8.87% carbon, which predicts the incorporation of B_4C in the matrix material.

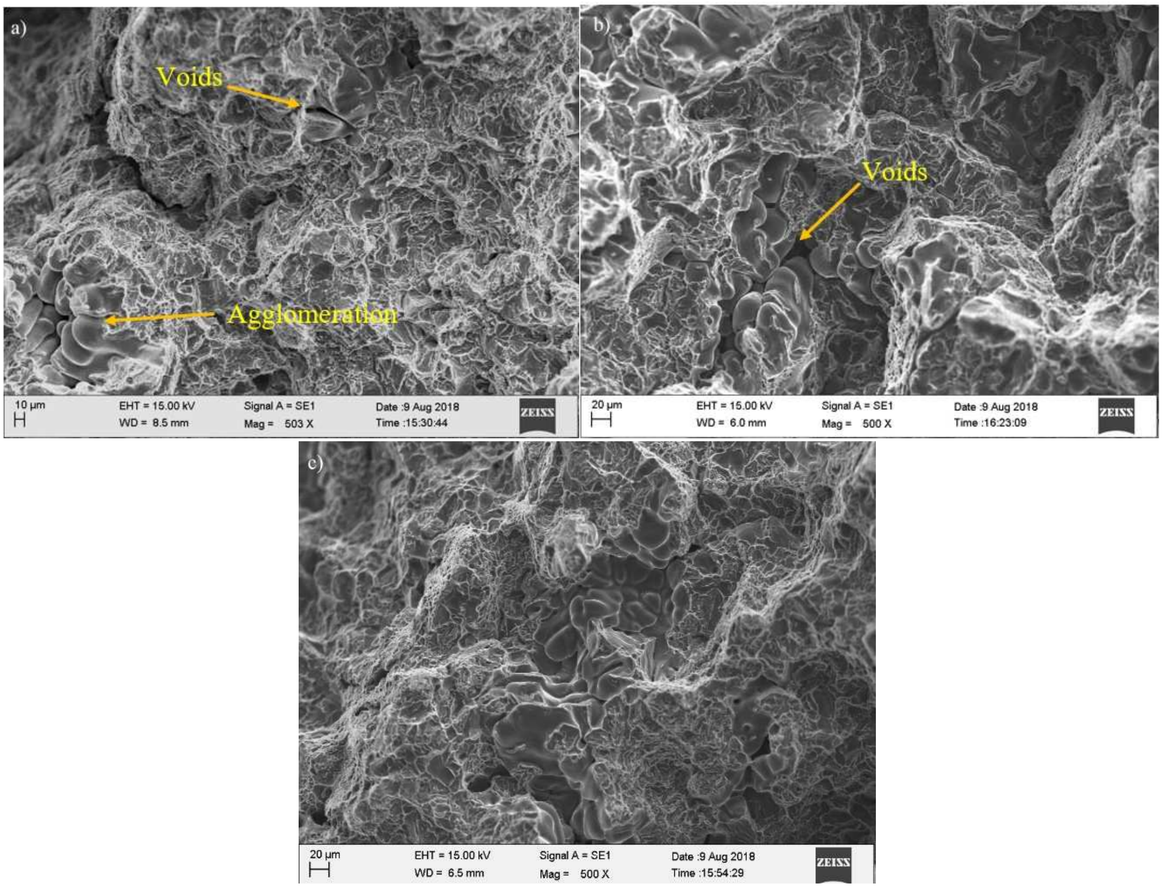

Figure 6: SEM Images of Fractured Surface a) 1% B_4C, 0.2%HEA, b) 2% B_4C, 0.4% HEA, c) 3% B_4C, 0.6% HEA

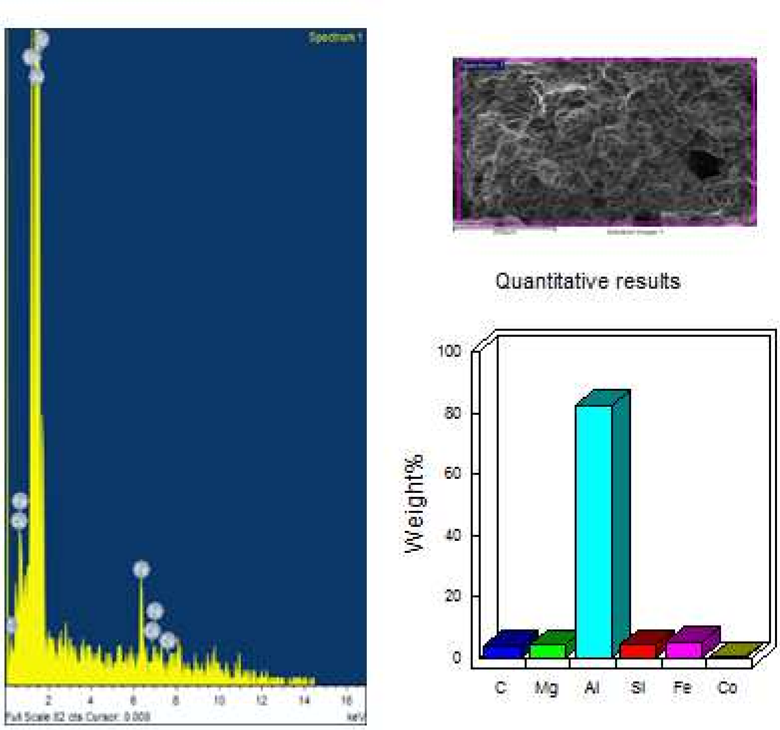

Figure 7: Energy Dispersive Spectrometry (EDS) Analysis of 3% B_4C, 0.6% HEA Hybrid Composites

CONCLUSIONS

Aluminum 6061 is reinforced with B_4C and HEA with different weight percentages using the stir-casting method. Hybrid metal matrix composites exhibited an increase in the hardness with an increase in the weight percentage of B_4C and HEA. The tensile properties decreased with increase in the B_4C and HEA. Aluminum generally is known as softer material compared to other metals, from the present study, hardness of the material can be increased by hybridizing the base alloy. These hybrid composites can be used as an alternative material for mild steel with respect to its increased hardness. Further, wear studies can be performed to understand the effect of reinforcement on base alloy; which will help to estimate the tribological properties along with mechanical behavior of the material.

ACKNOWLEDGMENTS

We convey our gratitude to Dr. B Satish Shenoy, Head, Department of Aeronautical and Automobile Engineering, MIT, Manipal for granting us access to the advanced composite laboratory for the testing purpose. We also thank Dr CHV Satyanarayana Raju, RCI, DRDO Hyderabad for providing us with reinforcement material. The authors also thank Dr. Sathyashankara Sharma, Head, Department of Mechanical and Manufacturing Engineering, MIT, Manipal for granting permission to use fabrication and machine shop for the preparation of specimens.

FUNDING

This work was supported by the Manipal Academy of Higher Education, Manipal-576104, INDIA.

CONFLICT OF INTREST

The authors declare there is no conflict of interest in this study.

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